COMMERCIAL LIGHTERING OPERATIONAL ASSESSMENT STUDY

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by

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Performed Under Office of Naval Research BAA 01-023
"Skin-to-Skin Connected Replenishment"

Commercial Lightering Operational Assessment Study

Introduction

This study was performed by Seaward International, Inc. under a subcontract from John J. McMullen Associates, Inc. (JJMA), under Office of Naval Research BAA 01-023 “Skin-to-Skin Connected Replenishment”.

The focus of this study is connected ship-to-ship naval operations under sea conditions equal to a minimum of Sea State 3 and a maximum of Sea State 5. For reference, these sea states are defined below for a fully arisen sea.

	Sea State 3	Sea State 5
Average 1/10 Highest Waves	4.2’-5.8’	10’-16’
Significant Wave Height	3.3’-4.6’	8’-12’
Average Wave Height	2.0’-2.9’	5’-7.9’
Average Wave Period	4.0-4.6 sec.	5.7-6.8 sec.
Average Wave Length	59’-71’	111’-160’
Wind Velocity	14-16 knots	20-24 knots
Description	Small waves, becoming larger; fairly frequent white horses.	Large waves begin to form; the white foam crests are more extensive everywhere. (Probably some spray.)

Note that the significant wave height is defined as the average of the one-third highest waves.

In performing this study, Seaward personnel interviewed operational personnel involved in tanker-to-tanker lightering operations off the coast of California (ChevronTexaco Shipping Co., LLC in San Pedro, California), FPSO (Floating Petroleum Storage Offshore) operations off the coast of Africa (ChevronTexaco Shipping Co., LLC in San Ramon, CA), and in third-party lightering operations worldwide (Fender Care Marine, Ltd. of Seething, Norfolk, UK). These operations cover a wide variety of vessel types and operational requirements, and also cover a wide range of wind, sea and swell conditions.

Seaward personnel also reviewed available literature, including the Oil Companies International Marine Forum “Ship to Ship Transfer Guide (Petroleum)” and “Mooring Equipment Guidelines”. A search of several web sites related to marine fenders, ship-to-ship transfer (lightering), synthetic lines, etc. was also performed.

In addition, Seaward project personnel have been involved in designing marine fenders and related equipment for almost thirty years. This includes ship-to-ship fenders and related equipment. This experience has also been factored into this study.

A Description of a Typical Lightering Operation

Each lightering operation is somewhat different, depending upon the particulars of the vessels involved, the equipment available for the operation, the operational procedures of the particular organization, and the environmental conditions during the operation. This description, therefore, is by necessity general, but may give an idea of some of the parameters that are involved.

For our example, let us assume the following vessels are involved. Vessel 1 is arriving with a full load of cargo (crude oil), and Vessel 2 is a dedicated lightering vessel arriving in ballast.

	Vessel 1	Vessel 2
DWT Tonnage, metric tons	304,000	156,800
Max. Displacement Tonnage, metric tons	350,000	180,950
Displacement in Ballast Condition, metric tons	--	92,000
Length, meters	339	274.5
Beam, meters	53.2	50
Draft, meters	21.9	17.2

Prior to the operation, mooring plans have been established, showing the location of winches and bitts and the mooring line arrangements planned for the operation. Checklists have been prepared and agreed upon. The weather and seas conditions in the lightering area have been checked to ensure that satisfactory conditions exist for the operation.

The larger vessel, Vessel 1 in this example, sets a course and continues on this course at slow speed. For this example, Vessel 1 sets a course away from the wind and sea and steams at its lowest speed (just above the stall speed of the diesel engines). Vessel 2 maneuvers into a position astern and on the starboard side of Vessel 1. See Figure 1, taken from the OCIMF publication "Ship to Ship Transfer Guide (Petroleum)", page 16. Vessel 2 has positioned its fenders on the port side prior to making the approach maneuver.

Note that there are several ways commonly employed to bring the fenders out to the operation. They may be towed alongside by the lightering vessel in the approximate position that they will be used. They may be brought out on deck by a support vessel such as an offshore supply boat and passed to the lightering vessel. In our example, Vessel 2 is a dedicated lightering vessel with the fenders in davits; therefore they are brought out to the site stowed in their position on deck and lowered into the operational position by the davits prior to the maneuvering operation.

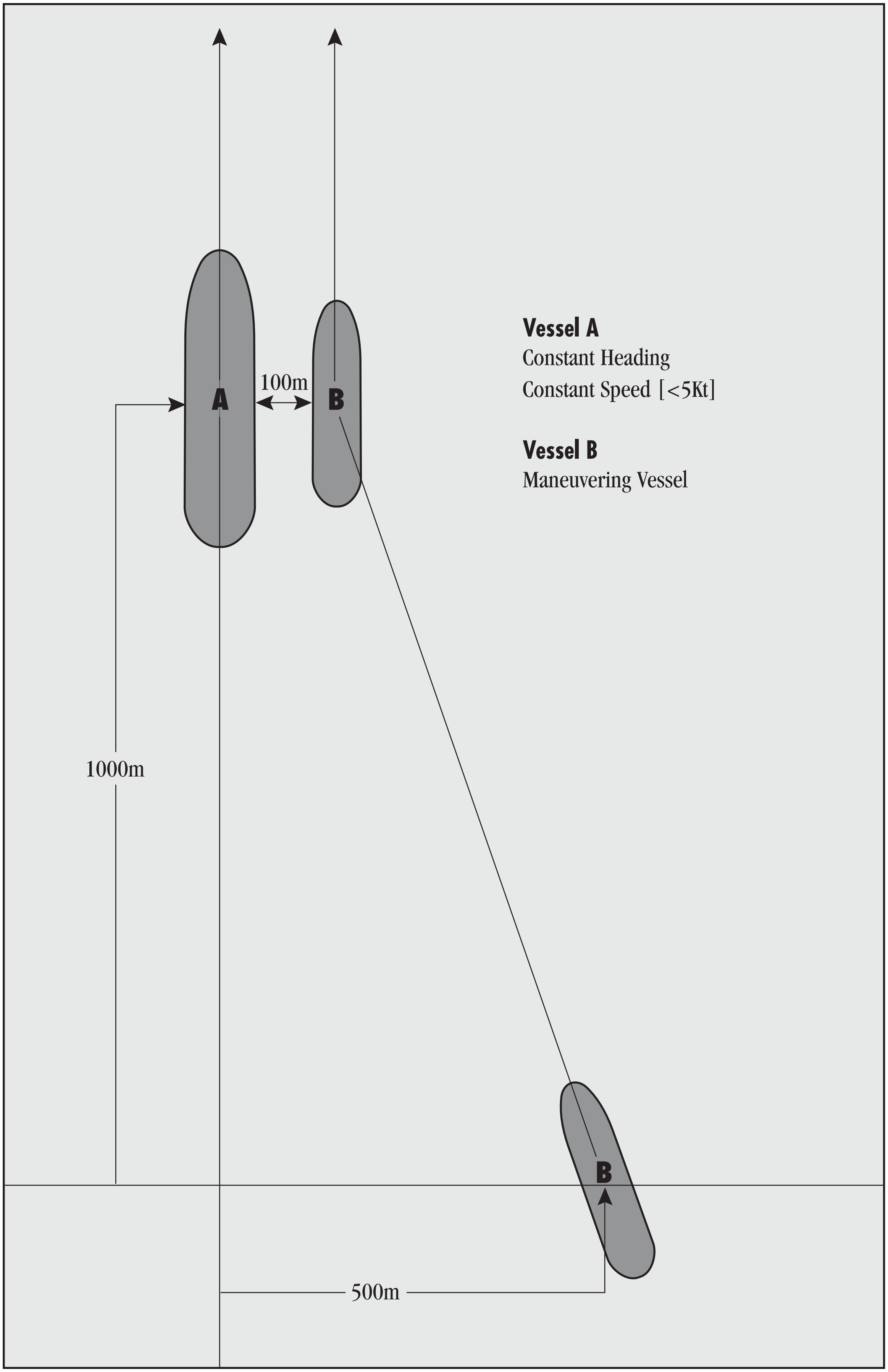


Figure 1 – Recommended Approach Maneuver

The fenders utilized are large pneumatic or foam filled fenders with chain and tire nets, and are deployed floating in the water with appropriate mooring lines. Vessel 2 maneuvers until it is within 50 to 100 meters from Vessel 1 and is on a parallel course with Vessel 1 and has the same forward speed as Vessel 1. Messenger lines are passed between the two ships and are used to haul mooring lines between the two ships.

For our example the mooring plan shown on page 19 of the OCIMF publication "Ship to Ship Transfer Guide (Petroleum)" is utilized. See Figure 2. Specialized mooring grommets that are designed to have a certain amount of stretch may be employed in the mooring lines. One end of each line is attached to a mooring winch; the other end is attached to a bitt on the other ship. Quick release hooks may be used on the bitt end of the mooring line if available.

The two ships approach until contact is made with at least one fender. Gradually tension is taken on the mooring lines until the two vessels are alongside with both vessels contacting all fenders (four fenders in this example).

For our example, a calculation can be made of the energy to be absorbed by the fenders during the berthing. Worksheet 1 in the appendix shows this calculation. The displacement tonnages and operating drafts of both vessels are used in the calculation (Vessel 1 at full load and Vessel 2 at ballast condition). In the calculation a berthing velocity of 0.15m/sec has been assumed, although in most cases the berthing velocity is generally much less than this value. Since the velocity term is squared in the energy calculation, even a slight increase in the berthing velocity can make a significant difference in the berthing energy, so it makes sense to be conservative. A berthing coefficient of 0.5 is used in the calculation. This assumes quarter-point berthing; under this assumption not all the energy of the two vessels is absorbed by the fenders, but a portion of the energy is translated into rotation of the ships. In our example, the berthing energy is calculated to be 51 ton-meters.

After the vessels are connected and the mooring lines have been secured, Vessel 1 ceases to operate its engine and puts its rudder amidships. Vessel 2 provides engine power and sets its speed at 1 to 2 knots. In this example, Vessel 2 steers so that the wind and sea are 5^0 to 10^0 off the port beam of Vessel 1. In this orientation, Vessel 1 provides somewhat of a lee for the fenders, and the roll of the vessels is minimized.

Oil transfer hoses are passed from Vessel 2 to Vessel 1 using Vessel 2's crane. In this example, two 12" hoses of approximately 25 meters length are used. The hoses are connected to Vessel 1's manifolds and pumping is started at a slow rate to check for leaks. When a safe operation is assured, pumping begins at its full rate through both hoses. This may take 12-16 hours, depending upon the amount of cargo being unloaded. When the transfer is almost complete, the pumping rate is again slowed down while the tanks are filled to the desired level.

After the transfer has been completed, the hoses are passed back to Vessel 2 and any excess cargo is allowed to drain out of the hoses.

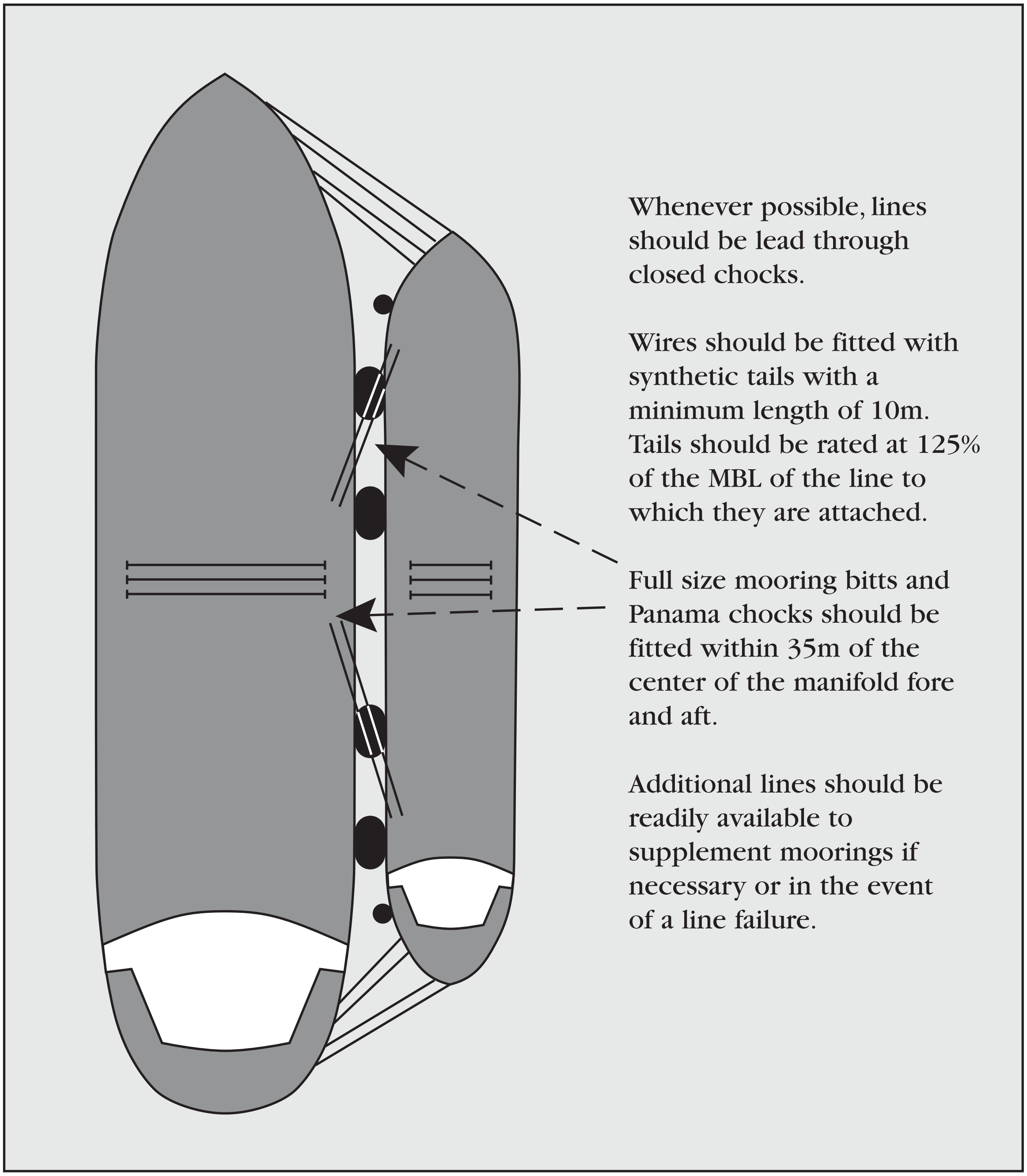


Figure 2 – Recommended Ship-to-Ship Mooring Arrangement

At this point the unmooring operation can commence. Vessel 2 slows down as much as possible while still maintaining steerage. The mooring lines are allowed to go slack and the ships begin to separate. When the ships are well clear of each other, they can begin to increase their speed and go their separate ways.

A calculation can also be made of the fender energy requirement if the two vessels make contact while unmooring. Now Vessel 1 has less cargo, but Vessel 2 is fully loaded. (See Worksheet 2 in the appendix.) For this example, the berthing energy is calculated to be 68.8 ton-meters (based on a contact velocity of 0.15 m/sec).

In our example, this entire operation has taken approximately 30 hours.

Operational Methods

While the above example gives a general idea of a lightering operation, there are numerous operational methods that may differ from the example given. The following sections describe some of these differences.

A. Anchored or Underway Lightering

   A lightering operation can be conducted either with the vessels underway (as in the example above), or at anchor. Both types of operations are conducted in the marine industry today. In general, lightering operations at anchor are generally conducted under more benign conditions than underway lightering operations. For example, operators report that tanker lightering operations take place offshore at anchor in the Gulf of Mexico in conditions up to 6'-8' seas.

   In some cases, Gulf of Mexico operators will maneuver while underway until the two vessels are moored together; then the larger vessel will drop its anchor on the side away from the lightering vessel, and transfer operations can begin. This operation has components of an underway lightering and components of a lightering operation at anchor.

   By comparison, operations are conducted in 12'-14' seas offshore California when both vessels are underway.

   Being underway allows the operator to choose the optimum heading with respect to the prevailing sea, swell, wind and current. The choice of heading differs depending upon the operator, but the goal is to minimize relative ship motions (especially roll) and to minimize fender motions.

   Experienced mooring masters recommend that the Navy plan for maximum flexibility, and thus plan both for anchored and underway ship-to ship transfer operations.

B. Upwind or Downwind Lightering Operation (for Underway Lightering Operations)

As mentioned above, underway lightering operations permit the operator to choose the optimum orientation with respect to the wind and swell. Some operators head into the prevailing wind and swell; others head away from the prevailing wind and swell. Often they will head 5-10 degrees off of the direct heading relative to the wind and swell, to allow the larger ship to create a lee for the fenders.

Chevron-Texaco lightering operations offshore California are generally conducted heading away from the prevailing wind and swell. This reduces the relative wind speed and increases the relative period of waves into which the vessels are heading.

C. Velocity of Vessels (for Underway Lightering Operations)

During an operation, the lightering vessels must have enough velocity to maintain directional control, but not so much that they create suction forces between the vessels. In general, this means as low a forward speed as possible, typically just one to two knots according to OCIMF publications. Most diesel engines used on vessels are not designed to operate at low speeds, so this can create a problem in maintaining sufficiently low velocities. If a purpose-built ship is used as a lightering vessel, it can be equipped with controllable reversible propellers and bow thrusters, to give good control at low speed, without relying entirely on a low engine speed.

The velocity is particularly critical during uncoupling operations. If the velocity is greater than approximately 2 knots, the Bernoulli effect due to the flow of water between the two ships creates such a large amount of suction force that the vessels can not easily separate. This is an additional argument for the use of bow thrusters and controllable pitch propellers when the ship is purpose-built for lightering operations.

D. Relative Draft of the Lightering Vessels

When a lightering tanker approaches a fully-loaded VLCC or ULCC, it may have 50’ of freeboard, compared to approximately 20’ for the VLCC or ULCC. As the VLCC or ULCC transfers cargo to the lightering vessel, these freeboard heights essentially reverse. When the lightering tanker uncouples from the VLCC or ULCC, it may have a 20’freeboard, and the VLCC or ULCC may have a 50’ freeboard. This is an important consideration because the lines rigged between the two vessels may have a significant vertical component, and the angle of these lines changes during the operation.

It also leads to the requirement that the chocks be able to accept lines having vertical loads as well as horizontal loads. For this reason, closed Panama chocks are recommended for use in lightering vessels.

For more details, refer to pages 62-63 of the OCIMF publication "Mooring Equipment Guidelines", 1997 edition.

E. Dedicated Lightering Vessel versus Vessel of Opportunity

Use of a dedicated vessel for lightering versus a vessel of opportunity lets operators optimize their equipment for the operation. A dedicated lightering vessel, for example, may be equipped with fender davits. This allows the fenders to be lifted out of the water and stored on deck during transit to and from the lightering operation. If the vessel is not equipped with fender davits, the fenders must either be towed out to the lightering area by the lightering tanker or brought out by a support vessel. Having the fenders out of the water for transit significantly increases the speed of transit. Fender davits used by ChevronTexaco's dedicated lightering vessels are manufactured by Edgewater Machine & Fabricators, Inc. of Edgewater, Florida. (See Figure 3.)

When a dedicated vessel is used, rigging for the fenders can also be dedicated and optimized for the operation. Quick-release hooks for the lines that connect the two vessels can be permanently mounted. Strain gages can be employed on the quick release hooks, giving a real-time readout of the line loads during the operation.

A crane for handling the hoses that transfer the cargo can be located in an optimal position on a dedicated vessel.

Bow thrusters and controllable reversible propellers, when used on a dedicated vessel, give better low-speed control and better control in coupling and de-coupling operations. Similarly, rudders can be specially designed on a dedicated vessel (45° versus 35° rudder, for example) to give greater control, particularly during low-speed coupled operations.

If a dedicated vessel were designed from the ground up, additional features could be added. The vessel could have additional parallel midbody, giving additional length over which to place the fenders. It could potentially be designed with roll stabilization, or with a hull form that would give improved stability, particularly in roll.

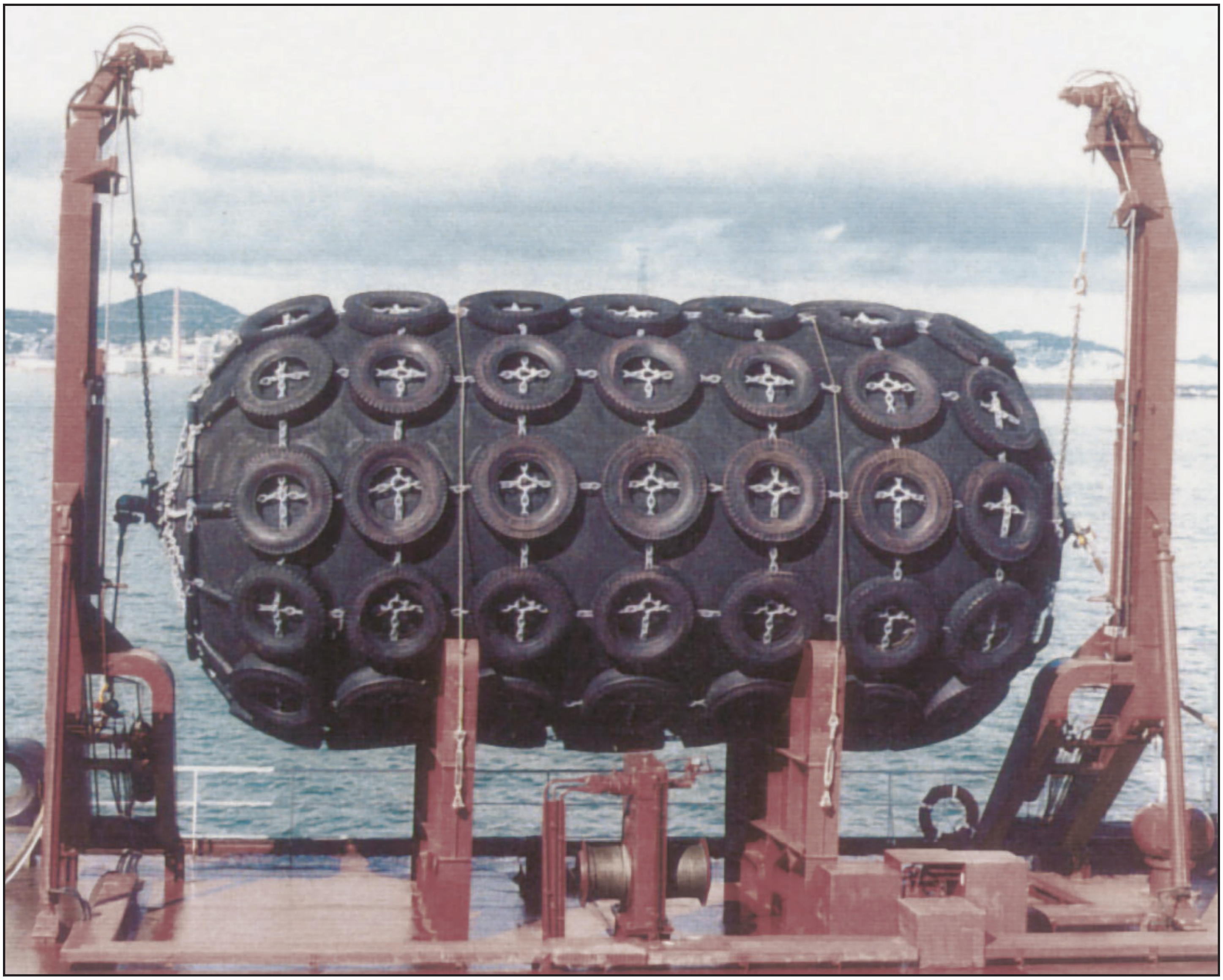


Figure 3 – Dedicated Fender Davit

F. A Special Case: Fluid Transfer using Tandem Operations

ChevronTexaco's San Ramon, California personnel have considerable experience with moored offshore storage vessels (FPSOs). While these vessels have been designed for transfers with a lightering vessel alongside, the operators prefer where possible to operate the vessels in tandem, rather than alongside. (See Figure 4.) A floating hose is used between the two vessels, and an auxiliary vessel (offshore tug) is used to maintain the position of the lightering vessel. The ChevronTexaco personnel report that this operation is less sensitive to sea state than a connected lightering. The Navy may wish to consider such an operation for transfer of aviation fuel or diesel fuel; however, it is obviously not applicable for the transfer of containerized cargo. Since the primary focus of this study is "connected" ship-to-ship operations, a detailed study of tandem operations is outside the scope of the current effort.

Fendering Methods

A. Primary Fenders

Primary fenders are the large fenders that are positioned along the parallel midbody of the ships. They are either foam or pneumatic. Both foam and pneumatic fenders work by compressing air, although in foam fenders the air is contained within small closed foam cells.

Pneumatic fender manufacturers are located in Japan (Yokohama Rubber Co. and Shibata Rubber Co.) and Korea (HS R&A), and foam fender manufacturers are located in the USA (Seaward International, Inc. and Urethane Products Corporation) and the UK (Balmoral, CRP and Hippo).

Pneumatic fenders may be 0.5 kg/cm^2 (7 psi) or 0.8 kg/cm^2 (11 psi) initial pressure. Foam fenders may be manufactured with Standard, Low Reaction, or High Capacity foam, corresponding to the different pressures of pneumatic fenders, but with a somewhat greater range of pressures.

Primary fenders are positioned at both ends of the parallel mid-body of the ship, with suitable fenders in between. The quantity of fenders used depends upon the sizes of the two vessels, as well as whether multiple vessels are anticipated. For many operations where the length of the smaller vessel does not vary (such as on a dedicated lightering vessel), a quantity of four fenders is commonly used.

If four fenders are used, the fenders can be utilized as a string of four fenders, or positioned in groups of two. Each group is typically positioned well forward and well aft on the parallel mid-body.

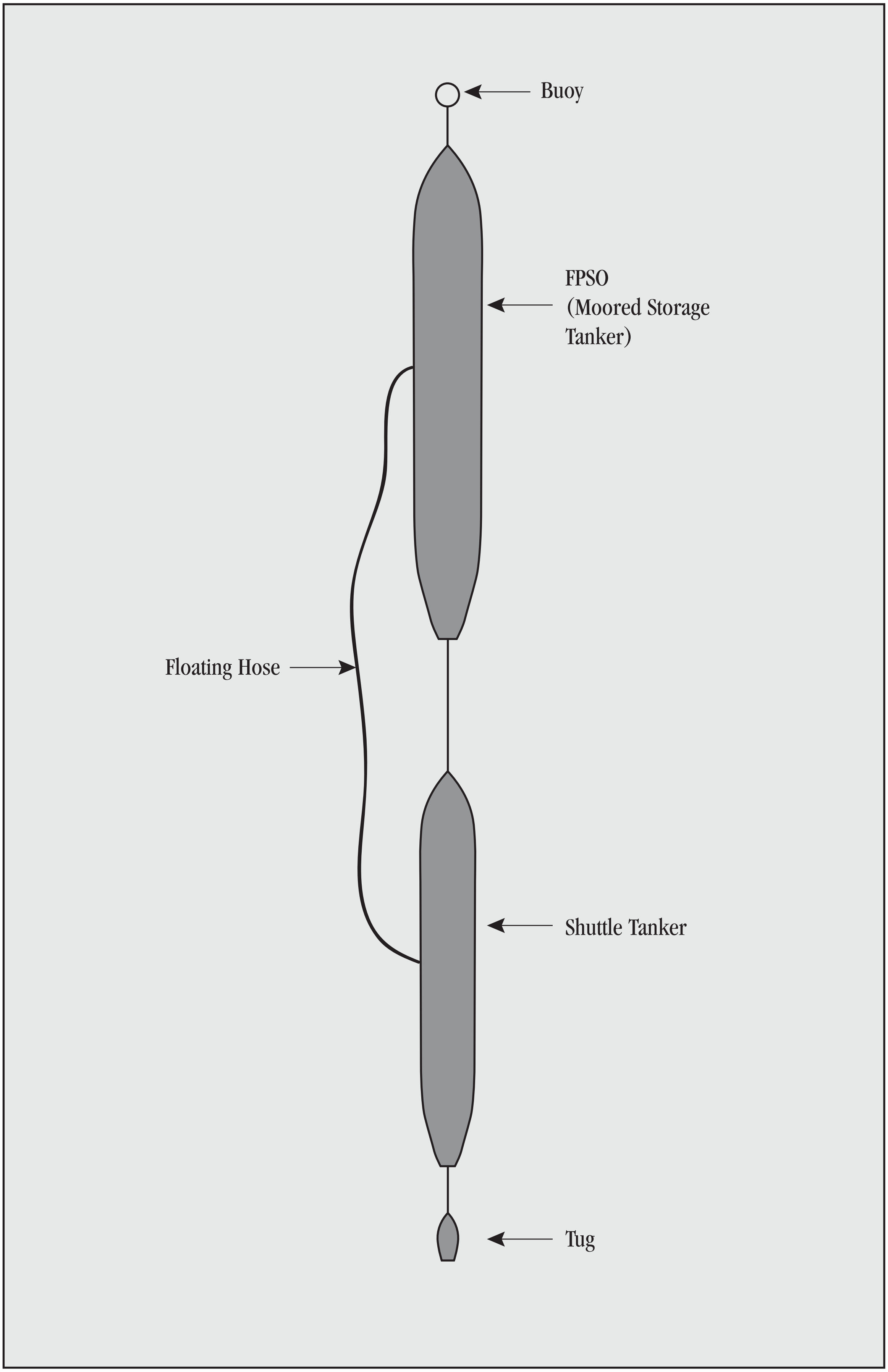


Figure 4 – Tandem Operations

ChevronTexaco, on their dedicated lightering vessels, utilizes the fenders in two groups of two. They feel this allows better control over the position of the fenders for their operations. ChevronTexaco's primary fenders are 4.5m x 9.0m (approximately 15' x 30') pneumatic fenders (0.5 kg/cm^2) manufactured by Yokohama Rubber Co. This same size pneumatic fender is used by ChevronTexaco's storage vessel (FPSO) offshore Angola. FenderCare utilizes primarily 3.3m x 6.5m (11' x 22') or 2.5m x 5.5m (8' x 18') pneumatic fenders as primary fenders, depending on the size of vessels being lightered.

Primary fenders are commonly used in the floating mode (i. e., not suspended). They are also commonly outfitted with chain and tire nets. The chain and tire nets help stabilize the fenders in the seaway, they provide protection against abrasion of the ship hull by the chain net, and they act as a longitudinal shock absorber. They also slightly increase the standoff between the vessels.

The quantity and size of fender can be best determined by reference to fender manufacturers' literature. However, the following table from the OCIMF publication "Ship to Ship Transfer Guide (Petroleum)" can be used if no other information is available.

Use the table after calculating C from the following equation:

$$C = \frac{2 \text{ x Displacement of Ship A x Displacement of Ship B}}{\text{Displacement of Ship A + Displacement of Ship B}}$$

QUICK REFERENCE GUIDE FOR FENDER SELECTION

C Displacement	Relative Velocity	Berthing Energy	Suggested Fender Quantity	Typical Fender Size
Tons	**m/sec**	**ton-meter**		**meters**
1,000	0.30	2.4	3 or more	1.0 x 2.0
3,000	0.30	7.0	3 or more	1.5 x 3.0
6,000	0.30	14.0	3 or more	2.5 x 5.5
10,000	0.25	17.0	3 or more	2.5 x 5.5
30,000	0.25	40.0	4 or more	3.3 x 6.5
50,000	0.20	48.0	4 or more	3.3 x 6.5
100,000	0.15	54.0	4 or more	3.3 x 6.5
150,000	0.15	71.0	5 or more	3.3 x 6.5
200,000	0.15	93.0	5 or more	3.3 x 6.5
330,000	0.15	155.0	4 or more	4.5 x 9.0
500,000	0.15	231.0	4 or more	4.5 x 9.0

The OCIMF publication notes that as it is not always possible to accurately judge approach speed, it may be prudent to err on the conservative side when selecting fenders.

B. Secondary Fenders

Secondary fenders may be either pneumatic or foam filled. They are normally somewhat smaller than the primary fenders and are suspended well above the waterline. (Some operators refer to them as “baby fenders”.) Their purpose is to protect bow and stern plating from inadvertent contact during mooring and unmooring. They are normally located forward and aft of the parallel mid-body.

Since these fenders are frequently suspended in positions with limited access to lifting gear or support points, it is advantageous for secondary fenders to be low in weight. Commonly, foam fenders without nets are used, although “sling type” fenders (i. e., pneumatic fenders without chain and tire nets) have also been employed. ChevronTexaco, on their dedicated lightering vessels, utilizes two 8’ x 12’ SEA GUARD foam-filled fenders manufactured by Seaward International, Inc. as the secondary fenders. The same type of fenders are also used on ChevronTexaco’s storage vessel (FPSO) offshore Angola.

Line Arrangement and Methods

A mooring plan should be adopted for each operation. The specifics of the plan will depend upon the size of each ship and the difference between their sizes, as well as the location of chocks and bitts. A general guide was shown earlier in Figure 2 as an illustration for a recommended and proven mooring plan for a ship to ship transfer operation in offshore waters (from the OCIMF publication “Ship to Ship Transfer Guide (Petroleum)”.

Care should be taken where possible to avoid concentrating loads by passing several mooring ropes through the same chock and onto the same mooring bitt.

ChevronTexaco has reported success with the use of 75’ long endless nylon grommets in each mooring line. These are 2.5” diameter nylon lines made by Whitehill Manufacturing of Lima, PA, arranged in an endless loop. There are two buoy splices in the grommets, one in each end. Canvas is wrapped in the wear area for chafing protection. ChevronTexaco has reported that they believe the endless nylon grommets made by Whitehill are one of the keys to their success in being able to conduct lightering operations in relatively heavy sea conditions.

In the ChevronTexaco operation, AmSteel Blue synthetic ropes manufactured by The American Group are used to connect the grommet until just before the chock. (This rope is made of high modulus polyethylene (HMPE) fiber, with a tradename of Dyneema or Spectra. It has low stretch, similar strength to a steel wire of the same size, and it floats.) A 9' length of 1.5" wire rope is used through the chocks. A 6' length of 1.5" wire rope is also used at the fender end of the mooring line.

Mooring Winch Use

Mooring winches are used at one end of the lines that are used to moor the vessels together. (The other end is on a bitt on the other vessel. Some operators, such as ChevronTexaco also use quick-release hooks connected to the bitt. This permits rapid unmooring of the vessels in an emergency.) The lines are brought snug at the start of the operation, with the amount of force in the lines relatively low.

The mooring winches on ChevronTexaco's dedicated lightering vessels have brakes rated at 56 tons. ChevronTexaco's dedicated vessels also have load monitors on all the vessel's mooring winches. Their captains report that they can watch a swell come past the vessel on the load monitors. The loads on the load monitors are generally less than 15-20 tons.

The ChevronTexaco mooring winches are manufactured in Japan by Nippon Pusnes Co. Ltd. They are operated with steam.

Some commercial lightering operators have investigated the use of constant tension winches on their dedicated lightering vessels. Their conclusion was that constant tension winches are prohibitively expensive for their purposes.

Fuel Transfer Methods

Fuel transfer involves numerous safety precautions, some of which are described in the OCIMF publication "Ship to Ship Transfer Guide (Petroleum)". These safety precautions involve such items as fire safety, grounding of electrical equipment, precautions against diesel exhaust (especially hot ash or soot), grounding of cargo hoses, transmissions from the ship's radio, use of the ship's radar, gas accumulation, electrical storms, galley stoves, unauthorized craft, etc. Another set of safety precautions relates to the transfer hoses themselves, as well as the hose connections.

A crane is generally located on the dedicated lightering vessel in a convenient position to handle the fuel transfer hoses. Location of mooring lines and fenders is done so that the fuel transfer area of the vessel (amidships) is clear of line tenders and other mooring personnel. On the ChevronTexaco dedicated lightering vessels, two 12" diameter hoses are utilized, giving a combined transfer rate of approximately 75,000 Barrels per Hour.

(One Barrel is equal to 42 gallons.) ChevronTexaco personnel report that the pumps that are used to transfer the fuel are operated by steam.

The OCIMF publication “Ship to Ship Transfer Guide (Petroleum)” gives fuel transfer rates for different size hoses at different manufacturers’ ratings (page 29).

Limitations of Existing Methods

Operators have continued to improve their equipment for ship-to-ship transfer and, in the process, have extended the limits of the operation.

The operations conducted by FenderCare Marine are typical of most conventional lightering operations. In this case the vessels average 40,000 to 50,000 tons in size and utilize fenders with typical dimensions of 3.3m diameter by 6.5m length. Wave height limitations of 6’-7’ are typical of this type of operation.

ChevronTexaco’s California operations are among the best-equipped lightering operations, with dedicated lightering vessels, very large fenders, specially designed lines, highly professional crews, etc. Their guidelines allow for lightering operations to get underway (i. e., the start of the process of coupling the two vessels together) if the winds are 30 knots or less and the combined sea and swells are less than 10’. Once coupled together, operation can continue in 12’-14’ seas. The guidelines indicate that the vessels must break apart if the winds reach 45 knots and the combined sea and swells reach 16’.

These probably represent the limits of existing ship-to-ship transfer methods for this size of vessels.

Operators’ Recommendations for Improvements

Operators recommend that a purpose-built vessel have a longer parallel mid-body than a traditional vessel. This gives more separation between the forward and the aft fenders and therefore more protection to the vessel. A deeper and more full-bodied hull form should be considered to minimize motions, particularly roll.

They recommend that a purpose-built vessel have bow thrusters and a controllable reversible propeller. They also recommend the controllable propeller for vessels that will come alongside. Operators recommend that a purpose-built vessel have a larger rudder than standard as well as one with a greater angle of movement, say 45° versus 35°. It was also mentioned that a vessel with twin-screw propellers should be considered. Dynamic positioning (DP) was also mentioned, but was felt to be overly complex for the military’s operational requirements; in addition, concerns were expressed about the problems that would be caused in a dynamically-positioned vessel by a line accidentally dropped into the water.

Use of special lines as shock absorbers, such as the Whitehill grommets, is highly recommended. Use of synthetic lines that float is also recommended in other locations.

Quick release hooks are recommended, particularly for a military operation, where hostile action may require rapid uncoupling.

A specialized swivel that lets the fenders rotate without causing rotation in the fender rigging is recommended.

Operators recommend that operations be planned for transfer operations both underway and at anchor, to give maximum flexibility.

To minimize crane reach when container ships are alongside, operators recommend that fenders be installed on both the port and starboard side of the vessel and that cranes be designed to handle containers on both sides of the vessel. This will significantly reduce crane reach requirements.

A dedicated vessel should have lots of bitts and chocks. The chocks should be of the closed Panama type.

Dedicated tugs for bringing vessels alongside should be considered.

Good communications equipment between the two vessels is a must. Trained ship-to-ship transfer personnel is also a must. Planning for each transfer operation, with general arrangement plans, showing locations of bitts and chocks, as well as mooring lines is a must. Good operational checklists are a must.

Seaward's Assessment for Naval Applications

Seaward concurs with the general seamanship recommendations mentioned above. Because of differences in the military mission and commercial operations, however, we do have a few recommendations in addition to the above items.

Fenders for commercial operations are designed for low weight (so they can be easily lifted by davits), and they have regular inspections and maintenance. Commercial vessels are unlikely to be fired upon in their operational mission. Low cost is a priority in commercial operations.

Military missions have different priorities. High reliability is paramount. Fenders should perform even if they are hit by enemy fire. Low cost is important, but reasonable cost with high reliability is even more important. Frequent maintenance may or may not be available. Safety is a significant issue, particularly if a fender should be punctured.

Because of the differences in the commercial mission and the military mission, Seaward recommends foam-filled fenders versus pneumatic fenders for Navy use. These are available in approximately the same range of sizes and performance as pneumatic fenders. The cost difference is not prohibitive. Foam filled fenders are made in the USA and the UK. Foam fenders will function even if punctured. They are very safe, with over 25 years of operational history by the U. S. Navy with an unblemished safety record. Foam filled fenders also offer some degree of damping of the vessel motions, and are reported to reduce the magnitude of crane boom movements.

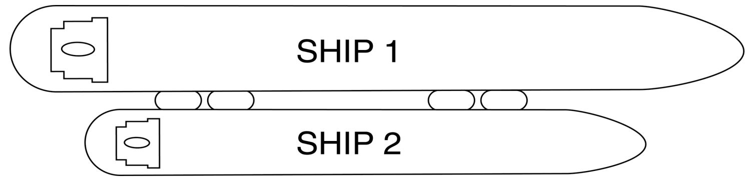
Seaward recommends the use of net-style fenders as the primary fenders; this style is also used for commercial operations.

Seaward recommends that the primary fenders be deployed from dedicated fender davits located on the vessel. At least four fenders should be utilized on each side of the vessel. Depending upon the range of vessel sizes that will come alongside, even more fenders may be required. In general, the minimum fender spacing should be no more than 30% of the length of the smallest vessel that will come alongside. Operationally, it will be simpler to have additional fenders (six or eight, instead of four, for example) rather than trying to constantly change fender locations for different vessels coming alongside. If barges or supply boats will come alongside, another set of smaller fenders will be necessary.

Seaward recommends that secondary fenders also be the foam filled type. (This is also the most common type of secondary fender used commercially.) Seaward recommends that the secondary fenders be suspended from simple one-sling davits with slide boards for storage. Netless foam filled fenders are recommended as the type of secondary fender. The Navy has well-developed specifications for this type of fender and has used them for many years. At least two secondary fenders are recommended on each side of the vessel where ship-to-ship transfer operations will be conducted.

SEAWARD INTERNATIONAL, INC.

FUNDAMENTAL ENERGY CALCULATION WORKSHEET (SHIP TO SHIP)



(NOTE) Use only SI units

		SHIP 1		SHIP 2	
M_b	*Displacement tonnage, t*	350,000		92,000	
D	*Draft, m*	21.90		8.75	
L	*Length, m*	339.00		274.50	
M_a	*Added mass = 0.807 $D^2 L$, t*	131,208		16,960	
M_i	*Effective Mass = (M_a + M_b), t*	481,208	(M_1)	108,960	(M_2)

M *Coupled Mass=*

$$\frac{[\ 481{,}208\ (M_1) \times 108{,}960\ (M_2)\ ]}{[\ 481{,}208\ (M_1) + 108{,}960\ (M_2)\ ]} = 88843.39\ (M)$$

Berthing coefficient, C_B 0.50

$$E = \frac{88{,}843\ (M) \times 0.50\ (C_B)}{2} \times (V^2)$$

$$E = \frac{22{,}211}{\quad} \times (V^2)\ Kn\cdot m$$

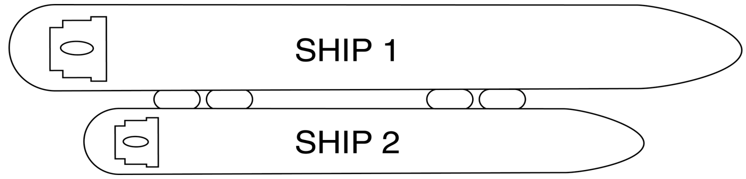
Velocity, m/s

Compute E for velocities considered:

m/s	kN· m	ft· kip	t· m	Fender Size, ft x ft or m x m
0.15	500	369	51.0	
0.00	0	0	0.0	
0.00	0	0	0.0	

SEAWARD INTERNATIONAL, INC.

FUNDAMENTAL ENERGY CALCULATION WORKSHEET (SHIP TO SHIP)



(NOTE) Use only SI units

		SHIP 1		SHIP 2	
M_b	*Displacement tonnage, t*	193,200		180,950	
D	*Draft, m*	12.10		17.20	
L	*Length, m*	339.00		274.50	
M_a	*Added mass = 0.807 D^2 L, t*	40,054		65,535	
M_i	*Effective Mass = $(M_a + M_b)$, t*	233,254	(M_1)	246,485	(M_2)

M *Coupled Mass=* $$\frac{[\ 233{,}254\ (M_1) \times 246{,}485\ (M_2)\ ]}{[\ 233{,}254\ (M_1) + 246{,}485\ (M_2)\ ]} = 119843.5\ (M)$$

Berthing coefficient, C_B 0.50

$$E = \frac{119{,}843\ (M) \times 0.50\ (C_B)}{2} \times (V^2)$$

$$E = \frac{29{,}961}{} \times (V^2)\ Kn \cdot m$$

Velocity, m/s

Compute E for velocities considered:

m/s	kN· m	ft· kip	t· m	Fender Size, ft x ft or m x m
0.15	674	497	68.8	
0.00	0	0	0.0	
0.00	0	0	0.0	

5/15/2002